

§ 11. Effect of Long Term Exposure to High Magnetic Field at Cryogenic Temperature on Martensitic Transformation of SUS316

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The cryogenic support structure in the LHD, which sustains the poloidal and helical coils, are constructed with austenitic stainless steel, SUS316, and is exposed to high magnetic field of around 3 T at 4.5 K for a long time. The SUS316 plate of which thickness is up to 100 mm was hot bent, machined and welded during the construction. To hold down the residual deformation, the post weld heat treatment was not performed and the carbon content was not reduced to keep rather high yield stress and ultimate tensile strength.

SUS316 has high nickel equivalent and a stable austenitic phase that is non-ferromagnetic. However, stability of the heat-treated and hardly machined austenitic phase has not been clarified under a long time exposure to high magnetic field at cryogenic temperature.

In this paper, solution heat-treated and sensitized samples were prepared and exposed to high magnetic field at 4.5 K during the LHD operation. Before and after the exposure the magnetization was measured by a squid system and the martensitic transformation was discussed.

The tested material was machined out from center of the left-plate for the helical coil can of which thickness was 70 mm. Sample #1 was machined to 4 mm x 4 mm x 3 mm and solution heat-treated. Sample #2 was 4 mm x 4 mm x 4 mm and sensitized after solution heat treatment to generate chromium carbide on the grain boundary. For the solution heat treatment, the sample was kept at 1323 K for 30 minutes in vacuum and furnace cooled. The sensitized heat treatment was carried out at 973 K for 100 hours in vacuum and furnace cooled. The heat treatment was performed using gold imaging furnace, so the cooling rate to below 500 K was rather higher. The samples were polished with #1000 emery paper and then heat-treated. The microstructure of Sample #2 is shown in Fig. 1. The chromium carbides are formed on the grain boundaries.

After the heat treatment, the magnetization was measured using a squid system (Quantum Design; Model MPMS-XL) and the samples were attached to helical coil cover with an aluminum tape. The 4th cycle cooling operation of the LHD started on August 28, 2000 and finished on September 24, then the plasma and the device experiments were carried out until February 15, 2001 and the warming operation was followed. All operation of the 4th cycle ended on March 15, 2001. The samples were kept at 4.5 K for almost half year and about 2.5 T was expected to act on the samples repeatedly during the experiments. After the exposure, the magnetization was measured again.

The results of the magnetization measurements are shown in Fig. 2. The sensitized sample was magnetized during the first measurement, before the 4th cycle. Since the

chromium carbide is ferromagnetic, the chromium carbide was magnetized resulting in increase of the magnetization of the sample. At the same time, very small amount of alpha prim martensite (bcc) was expected to be generated on the grain boundaries. However, Sample #1 did not show such magnetization and it is noted that chromium rich region would be transformed easily. On the other hand, there was no clear hysteresis after the 4th cycle. From the results, it is concluded that the austenitic phase of SUS316 would be very stable even for a long time exposure to high magnetic field at cryogenic temperature.

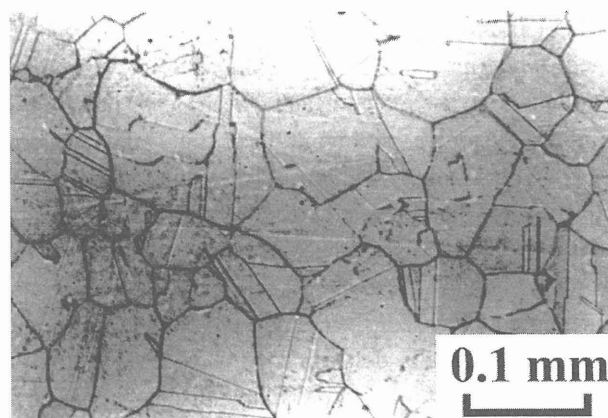


Fig. 1 Microstructure of solution heat-treated sample followed by sensitized heat-treatment.

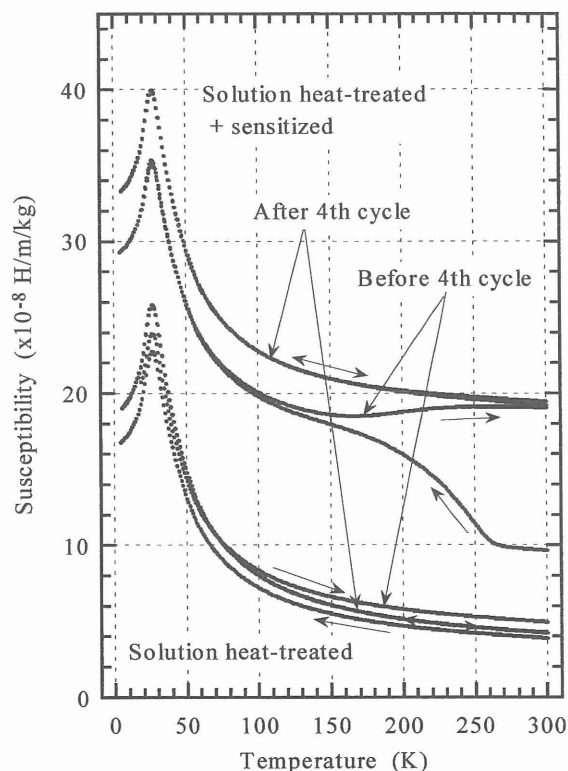


Fig. 2 Magnetization results of two samples before and after the 4th cycle of LHD operation. (Upper two data sets are obtained from the sensitized sample after solution heat-treated. Lower two data sets are measured on the solution heat-treated sample.)